A. Assumptions
1. Station will not begin final design until channel is certain
2. Preliminary work done well in advance
3. Tower reinforcement, antenna mounting, & transmission line included
4. Side-mounting of antennas for selected system is possible
5. Design is for single station on its own tower
6. Modelling of antenna interactions is not necessary

Task 8 - FCC Construction Permit Issuance

A. Assumptions
1. CP grant dependent only on technical design
2. CP grant not dependent on local approvals
3. CP grant in "nominal" time after application

Task 9 - Tower Alteration

A. Assumptions
1. Tower reinforcement required to support additional antenna/xmsn line
2. Required relocation of other antennas is minimal
3. Antenna can be mounted without major tower rebuild

Task 10 - Antenna Fabrication & Delivery

A. Assumptions
1. Antenna fab will not begin before CP grant
2. Contingent order placed well in advance to hold place for delivery
3. Antenna manufacturing capacity sufficient to meet demand

Task 11 - Antenna & Transmission Line Installation

A. Assumptions
1. Weather not a factor despite small slack time available

Task 12 - Local Zoning Permits

A. Assumptions
1. Zoning Permit required for extension of transmitter building
2. Zoning Permit granted in "nominal" time

Task 13 - Local Planning Approval

A. Assumptions
1. Plan approvals required for transmitter building extension

2. Plan approvals required for tower reinforcement & antenna addition
3. Plan approvals granted in "nominal" time

Task 14 - Building Construction or Alteration

A. Assumptions
1. Building construction/alteration is "fast-tracked"
2. Building construction/alteration on overtime basis

Milestone 15 - Auxiliary Link Spectrum Allocation

A. Assumptions
1. Separate STLs are required for Simulcast & NTSC channels
2. FCC allocates sufficient spectrum for Auxiliaries at time of Final R&O
3. Spectrum may be same as currently used for STLs, etc.
4. Spectrum sharing w/existing analog FM STLs is technically possible
5. Simulcast & NTSC Auxiliaries may share existing paths/channels

Task 16 - STL Frequency Search

A. Assumptions
1. Frequency search ultimately successful

Task 17 - STL CP & License

A. Assumptions
1. STL CP & license granted in "nominal" time

Task 18 - STL Antenna & Transmission Line Installation

A. Assumptions
1. STL antenna/xmsn line install cannot be delayed for good weather
2. Weather not a factor in installation completion within slack time
3. Adequate mounting space available without significant construction

Task 19 - STL Transmitter & Receiver Installation

A. Assumptions
1. STL transmitter/receiver installation in parallel with antenna/xmsn line
2. Adequate equipment space available in existing facility

Task 20 - Negotiate Telco STL

A. Assumptions

1. Local common carrier can interconnect Studio & Transmitter
2. Circuits available with good reliability & technical characteristics
3. Negotiations in parallel w/microwave frequency search, as backup
4. Microwave frequency search or channel sharing w/NTSC successful

Task 21 - STL Performance Analysis

A. Assumptions
   1. STL passes proof-of-performance test on first try
   2. Path reliability is good

Milestone 22 - STL Initial Use On Air

A. Assumptions
   1. STL put in use for NTSC operations as test
   2. If combined STL, helps transition to new system

Task 23 - Encoder Available

A. Assumptions
   1. Technical info to start encoder design available at time of NPRM
   2. Full technical documentation available at Final Report & Order
   3. No commitment to special ICs until Final Report & Order
   4. Encoders available in sufficient quantity to meet any demand

Task 24 - Exciter/Transmitter Available

A. Assumptions
   1. Technical info to start exciter design available at time of NPRM
   2. Full technical documentation available at Final Report & Order
   3. No commitment to special ICs until Final Report & Order
   4. Exciters & transmitters available in sufficient quantity

Task 25 - Transmitter Installation

A. Assumptions
   1. Transmitters available as needed without difficulty
   2. Support facilities must be constructed in transmitter bldg extension

Task 26 - Overall System Performance Analysis

A. Assumptions
   1. Overall Simulcast system passes proof-of-performance on first try
   2. Dummy load & antenna tests

Milestone 27 - Initial Test Signals On Air

A. Assumptions
   1. Station goes on air with test signals until Program Test Auth. received
   2. Test signals used for field test of new system

Task 28 - FCC Program Test Authority

A. Assumptions
   1. FCC grants immediate, automatic Program Test Authorization by FAX

Task 29 - FCC License Grant

A. Assumptions
   1. FCC grants final license with moderately short turnaround

Milestone 30 - Initial Programming On Air

A. Assumptions
   1. Program Test permits airing programming until license received

- IS/WP2-0164.
17 DEC 91

WTTW
Chicago

5400 North St. Louis Avenue
Chicago, Illinois 60625
(312) 583-5000
FAX (312) 583-3046

FAX Transmission

Date: 13 December 1991

To: Merrill Weiss

Fax Number: (908) 906-0907

From: Lolly Crofton

Fax Number: (312) 583-3046

Remarks:

Pages to follow: 10

If you do not receive all pages, please telephone: (3

Channel 11

WTTW
Chicago

Memorandum

13 December 1991

To: Merrill Weiss - Fax: (908) 906-0907

Fr: Lolly Crofton Lolly

It appears from my notes and the 24 January 1991 date of Larry's letter to you, that we were waiting for your response before continuing.

On 27 February 1991 I spoke to Seth Elliott about a meeting he attended in January 1991 in Washington, DC chaired by Jules Cohen and attended by antenna manufacturers. My notes are sketchy, but the gist of it was that antenna manufacturers felt it was putting the chicken before the egg to discuss particulars before a transmission system was chosen. They were sure an antenna could be built, but "...tell us what you need."

My last note was dated 4 March 1991 that I had left a message on your answering machine. We obviously never held a March meeting as mentioned in Larry's letter to you.

Please let me know how you'd like us to proceed.

January 24, 1991

S. Merrill Weiss, Vice Chairman
Implementation Subcommittee Working Party 2 on Transition Scenarios
c/o NBC
30 Rockefeller Plaza
Room 1600 W
New York, New York 10112

Dear Merrill:

On Monday, January 14, 1991 at 10:30 AM, eleven representatives (see exhibit one) of the thirteen television stations licensed to operate in Chicago convened to discuss the implementation of High Definition Television in our market area.

I briefed everyone on your letter to me and gave everyone a quick outline of the job at hand.

Seth Elliott, consulting engineer, Communications Site Management then passed out rooftop profiles (attached as exhibits two and three) of the John Hancock building and Sears Tower, the two transmission sites utilized by television broadcasters in the Chicago area. He noted that WBBM Channel 2 now has a circularly polarized antenna mounted in place of the bat wing shown on the drawing. Seth informed everyone that there is no vacant space at the John Hancock site on either mast to install any new antennas. He thinks that the wind loading of the antennas on the east tower is at the maximum allowed by the structural engineers but that the west tower is not at the maximum limit. However, the building as designed and constructed would allow a 100 foot mast to be erected between the two existing masts. Seth felt that the position of this mast could adversely effect the patterns of existing NTSC broadcasters using the east and west towers and the pattern of any HDTV broadcaster using the new tower.

At the Sears Tower site, the Channel 50 UHF (55 foot) pylon antenna on top of the west tower is not being used and could be removed and used for future HDTV antenna space. In addition, there is 14 feet vacant on the west tower and 29 feet vacant on the east tower.

In total, at the John Hancock site 700 feet of tower space is being used and at the Sears Tower site 500 feet of tower space is being used. At John Hancock WBBM Channel 2 has a circularly polarized main antenna and a horizontally polarized standby antenna; WMAQ

Channel 5 and WGN Channel 9 also have horizontally polarized main and standby antennas. At Sears Tower WLS Channel 7 has a circularly polarized main antenna and a horizontally polarized standby antenna; WTTW Channel 11 has both horizontally polarized main and standby antennas.

Some discussion centered around the possibility of placing future HDTV antennas on the planned "new world's tallest building." Construction was to have started last September but it did not start as planned and now with recession under way and the real estate market in Chicago already tremendously overbuilt it seems very unlikely that this building will be constructed anytime in the near future. It also appears that only one 200 foot mast will be constructed on the top of the building and some concern was raised as to who was going to manage the roof and if they would be sympathetic to television broadcasting.

There seemed to be a general consensus among those attending this meeting that if the channels that would be allocated to this group of broadcasters were all UHF channels, the broadcasters could work together to possibly utilize an all-channel UHF antenna or antennas at each site to broadcast HDTV signals. Attached is the antenna specification (exhibits four, five and six) of a manufacturer that claims to have a broadband UHF antenna in its product line. However, no one at the meeting was aware if this antenna would be applicable to HDTV transmissions. Seth Elliott is going to contact Giza Dienas of Andrew Corporation, and Bernard Hoelting of WCIU Channel 26 is going to contact Tom Vaughn of MCI to try and determine if such an antenna could be built.

Of course since no one knows which system will be chosen it is very difficult to try to determine antenna input power transmission line size and transmitter output power. However, if the power requirements were 20 Db below today's NTSC levels it certainly would be easier to implement any HDTV system in this city given the limited antenna space available.

There was also consideration given to the possibility of utilizing time division multiplexing of all signals at each site. There was some concern with this scheme, however, because of the active circuits involved and each broadcaster could possibly have trouble controlling their own signals. Nevertheless, there seemed to be no concern with the sharing of a common transmitting antenna and using a combiner to bring the high level signals together.

At both transmission sites there probably will be difficulty in obtaining additional floor space to accommodate transmitters of the size comparable to existing NTSC transmitters, but if the power levels are significantly reduced, such as 20 Db, it was thought that a 10 Kw UHF or a 1 Kw VHF transmitter certainly could be more easily accommodated. It appears that both transmission sites could accommodate the transmission lines necessary to plumb any antennas.

Thought was also given to the possibility of replacing some large UHF antennas, especially at the John Hancock transmitting site, with smaller more efficient antennas to allow for installation of HDTV antennas. One possible option for NTSC broadcasters with existing standby antennas at each site would be to remove these antennas and replace them with HDTV antennas or broadcast from their standby antenna and replace their main with an HDTV antenna. Another option discussed would be for each broadcaster to modify their existing NTSC antenna to allow space for their own HDTV antenna, although this scenario seemed more difficult to implement than the sharing of common antennas.

Another point that was discussed was that each broadcaster would probably like to have their HDTV transmitter and antenna at the site they are using now for their NTSC transmitter, which would certainly reduce maintenance, labor, and travel cost. One issue that was discussed was the possibility of having space available for some type of standby antenna. Some broadcasters thought that during the initial implementation of HDTV there would be no requirement for standby equipment but when HDTV became the dominant broadcaster vehicle, certainly standby antennas and transmitters would be necessary.

For you, Merrill, the one question that kept coming up around the table as we discussed the aforementioned issues was the allocation issue. If you could possibly give us some direction as to what the feeling is on how allocation is going to be determined it would be very helpful. We kept coming back to the same stone wall: will existing VHF licensees receive VHF HDTV allocations and UHF licensees receive UHF HDTV allocations? In fact, WBBM the channel 2 broadcaster does not want a low band VHF HDTV channel.

It is my plan to hold another meeting sometime in March to review with the Chicago broadcasters the information we have received from the various antenna manufacturers and any allocation information that you can give us to better formulate a tentative plan to implement HDTV in the Chicago area.

Sincerely,

Larry W. Ocker

Larry W. Ocker
Chair

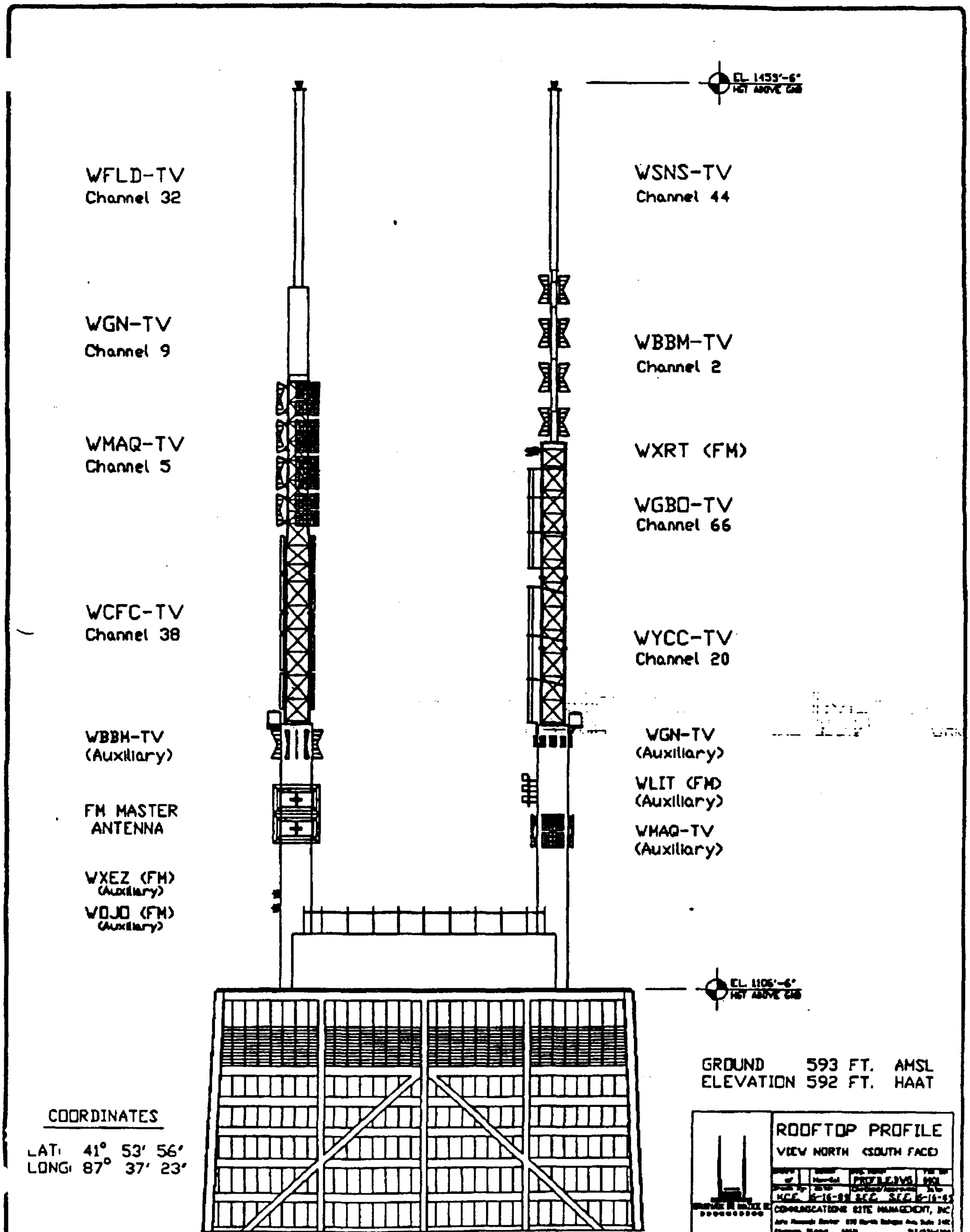
Attachments: exhibits 1 thru 6

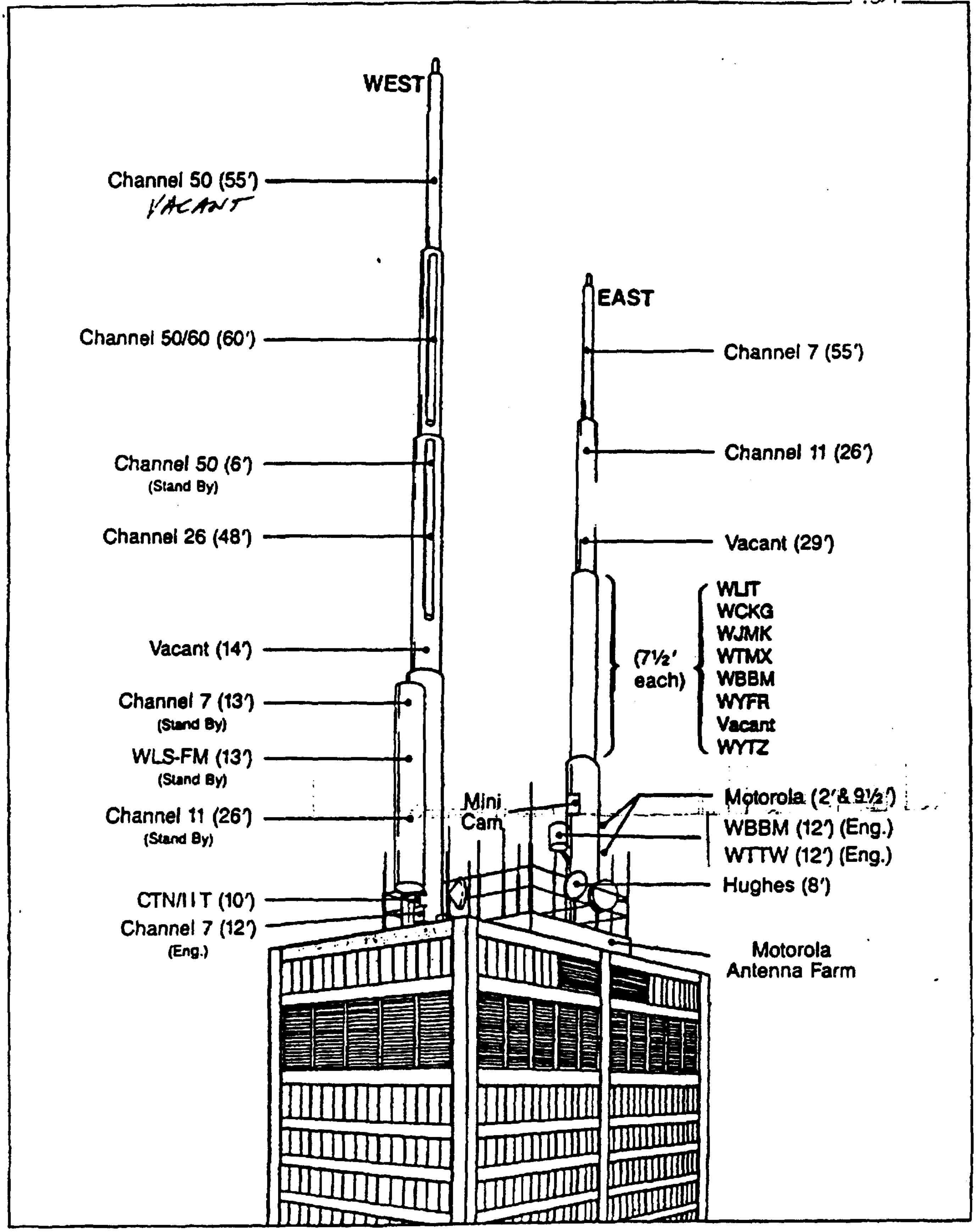
cc: Attendance
Dana Baifus/WEHS 60, Sears
Craig Beardsley/WSNS 44, Hancock

EXHIBIT ONE

Attendance

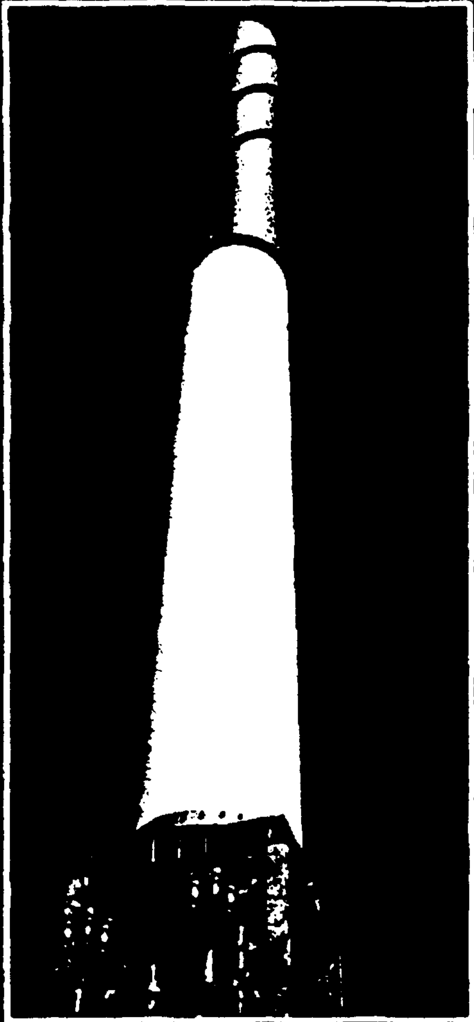
Norman Block/WCFC 38, Hancock
Mike Bock/WMAQ 5, Hancock
Lolly Crofton/WTTW 11, Sears
Seth Elliott/Communications Site Management
Jerry Hanna/WTTW 11, Sears
Dave Haworth/WBBM 2, Hancock
Bernard Hoelting/WCIU 26, Sears
Chuck Jennings/WGBO 66, Hancock
Bob Minor/WPWR 50, Sears
Larry Ocker/WTTW 11, Sears
Jim Owens/WLS 7, Sears
Tom Powers/WMAQ 5, Hancock
Don Rhodes/WYCC 20, Hancock
Dwain Schoonover/WFLD 32, Hancock
Craig Strom/WFLD 32, Hancock
Bob Strutzel/WGN 9, Hancock


EL. 1453'-6"
HGT ABOVE GND
WFLD-TV
Channel 32
WSNS-TV
Channel 44
WGN-TV
Channel 9
WBBM-TV
Channel 2
WMAQ-TV
Channel 5
WXRT (FM)
WGBO-TV
Channel 66
WCFC-TV
Channel 38
WYCC-TV
Channel 20
WBBM-TV
(Auxiliary)
WGN-TV
(Auxiliary)
WLIT (FM)
(Auxiliary)
FM MASTER
ANTENNA
WMAQ-TV
(Auxiliary)
WXEZ (FM)
(Auxiliary)
WOJO (FM)
(Auxiliary)
EL. 1106'-6"
HGT ABOVE GND
GROUND 593 FT. AMSL
ELEVATION 592 FT. HAAT
COORDINATES
LAT: 41° 53' 56'
LONG: 87° 37' 23'
ROOFTOP PROFILE
VIEW NORTH (SOUTH FACE)
COMMUNICATIONS SITE MANAGEMENT, INC



Broadcast System Plan

UHF TURNSTILE ANTENNA



Frequency range	470 - 790 MHz
HRP circularity	±2.0dB 470 - 720 MHz ±2.5dB 720 - 790 MHz
Input impedance	50 ohms
Input connector	Single or twin 3⅛ or 6⅛ IEC (depending on power requirement)
Input VSWR	Either ≤1.10:1 across the band 470 - 790 MHz or ≤1.05:1 across single operating channel
Power rating	See table. Ambient temperature 40°C
Gain	*See table for max gain* including typical distribution feeder and VRP losses.
Physical dimensions	See *Fig. 2 overleaf.*

Frequency MHz	Aperture wavelengths	Max. gain dB	Power rating peak synch kW
470		9.8	26
600	8	9.4	23
790		8.9	20
470		12.6	52
600	16	12.2	46
790		11.7	40
470		14.2	78
600	24	13.8	69
790		13.3	60
470		15.4	104
600	32	15.0	92
790		14.5	80

Fig. 1 **Electrical performance summary**

HORIZONTALLY POLARISED [illegible] OMNIDIRECTIONAL
COMPLETE UHF BAND MULTICHANNEL
HIGH POWER TOP MOUNTED LOW WIND LOAD
[illegible]

EXHIBIT FIVE

UHF TURNSTILE ANTENNA

The ADC UHF Turnstile is a broad band, omnidirectional UHF antenna. Available in a range of apertures it features excellent access and total weather protection.

GENERAL DESIGN

The top mounted antenna has been designed to cover the UHF band from 470 to 790 MHz with the performance indicated in Fig. 1.

Housed in and completely protected by a 1m internal diameter [illegible] GRP cylinder the Turnstile is available in four apertures. At the mean frequency of 600MHz these are, 8, 16, 24 and 32 wavelengths. A GRP ladder runs the complete length of the cylinder giving excellent access to both the antenna itself and via a trap door in the steel top cover, to the lightning spikes and any aircraft warning lights.

Horizontal plane radiation patterns, measured on a production antenna, are shown across the band in Fig. 3 and vertical plane patterns are shown in Fig. 4 for 600MHz.

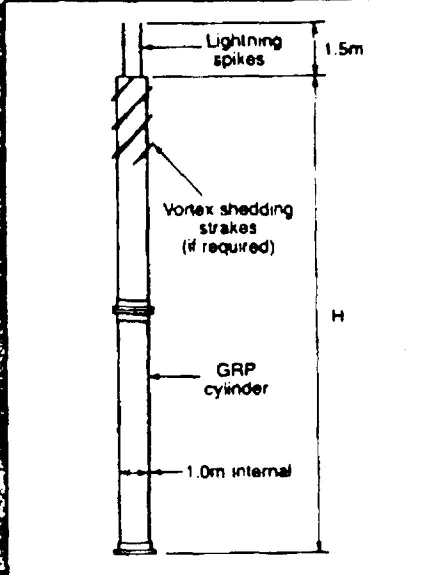
MECHANICAL DATA

The structural GRP cylinders for the two largest antennas (24 and 32λ) are made in two sections. For the smaller apertures the cylinders are in one continuous length.

All cylinders are mounted via a 1.2m diameter steel flange which has clearance holes for 32 x M24 bolts on a 1.12m diameter circle.

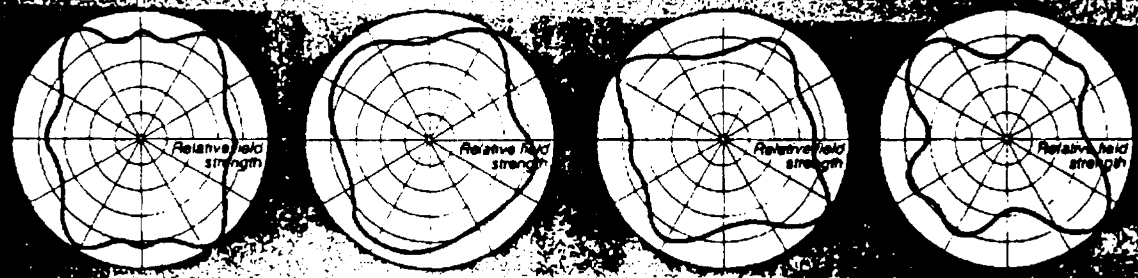
The table in Fig. 2 gives aerodynamic areas calculated in accordance with UK Standard CP3 for antennas without vortex shedding strakes fitted since these are required only in exceptional circumstances.

The quoted weights include the main input distribution power dividers which are mounted below the antenna cylinder.



Aperture wavelengths at 600MHz	Cylinder length H m	Aerodynamic area sq. m.	Approx. weight kg
8	5.35	4.1	700
16	9.35	6.9	1350
24	13.35	9.7	2000
32	17.35	12.5	3200

Fig. 2 **Physical dimensions**



470 MHz Max/mean gain 1.3dB · 620 MHz Max/mean gain 1.4dB · 720 MHz Max/mean gain 1.5dB · [illegible]

Fig. 3 **Measured horizontal plane radiation patterns**

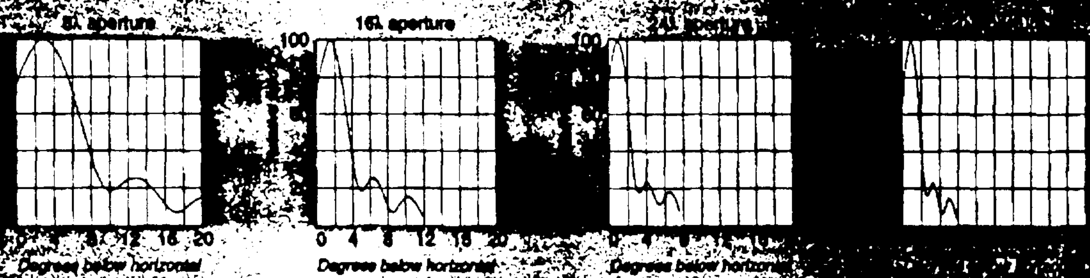


Fig. 4 **Vertical plane radiation patterns at 600 MHz**

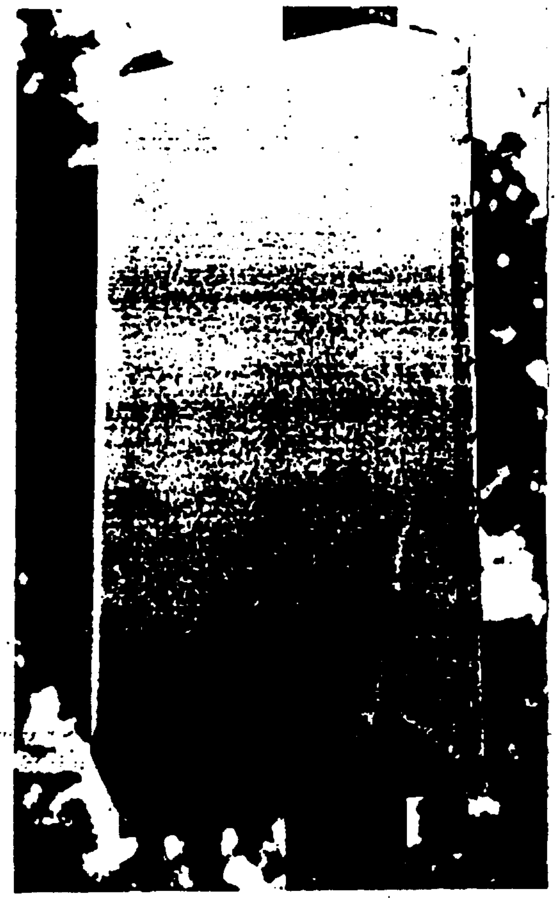
ADC Alan Dick & Co Ltd
Specialists in towers, masts and antenna systems

Alan Dick & Company Limited
The Barlands, London Road,
Cheltenham GL52 6UT, England.
Telephone: (0242) 518500
Telex: 43534 Fax: (0242) 510191

Alan Dick (Canada) Inc.
Alan Dick & Co. (Nigeria) Ltd.
Al Beward Alan Dick, UAE
LDL Communications Inc. USA

ALAN DICK &
COMPANY LIMITED

UHF BROADBAND PANEL ANTENNA



The newly developed 2λ UHF panel covers the complete band from 470 to 860 MHz. with a single model.

This horizontally polarised panel is ideal for situations whose frequency allocations are either not completely defined at the outset or which may be subject to change at a later date.

Equally well suited for incorporation in either standard arrays or custom designed systems the panel offers many of the versatile features of the long established Emislot UHF panel which are described in the Emislot brochure.

Features

★ *Low wind loading and weight.*
★ *Integral radome for increased stiffness and weather protection.*
★ *No pressurization required as far as radiating elements.*
★ *No electrical deicing required.*
★ *Good reliability, achieved using rugged simple design.*
★ *Competitive price.*

Electrical parameters

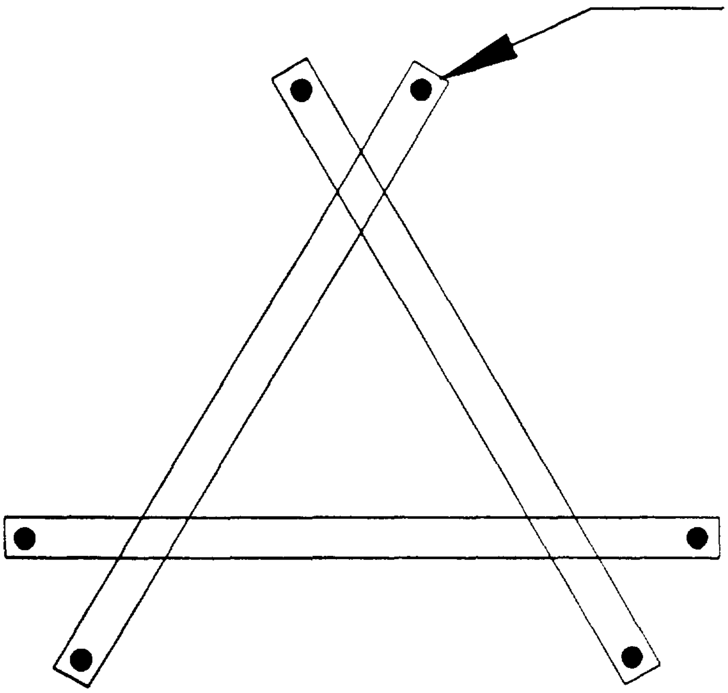
Operating frequency bandwidth	470 to 860 MHz
Input Impedance	50 Ohms
Reflection coefficient across band	1.10:1 VSWR
Horizontal radiation pattern with four panels mounted on 0.65m square, across band	Omnidirectional to ± 2db
Power rating	5 kWatts mean @ 860 MHz
Polarisation	Horizontal
Electrical length	2 wavelengths

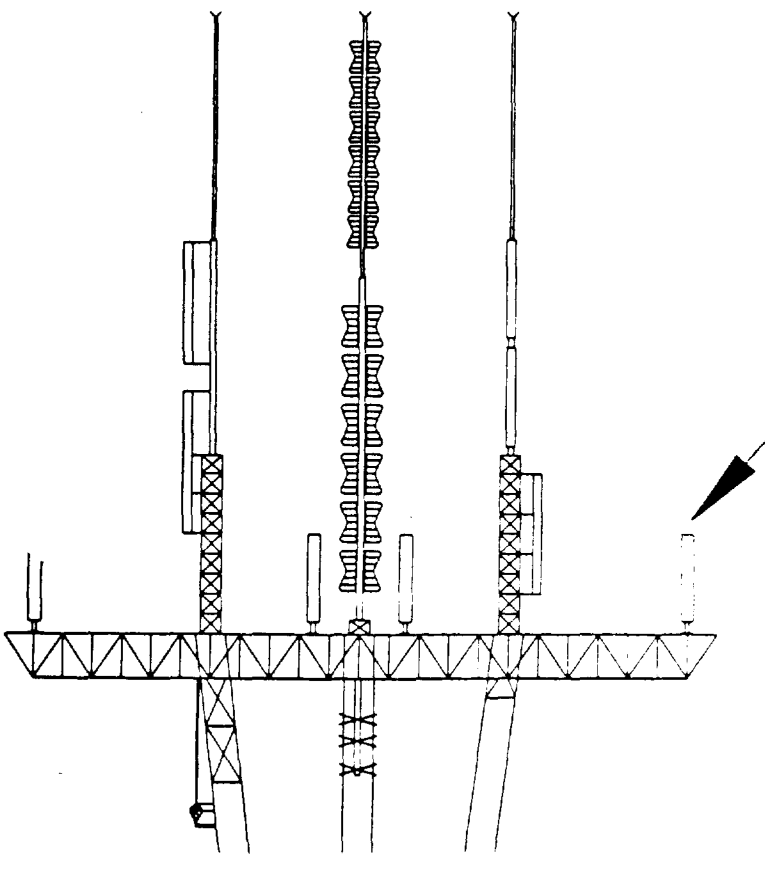
Mechanical design

Dimensions	1 x 0.25m x 0.5m wide
Input connectors	1 5/8 or 7/8 IEC

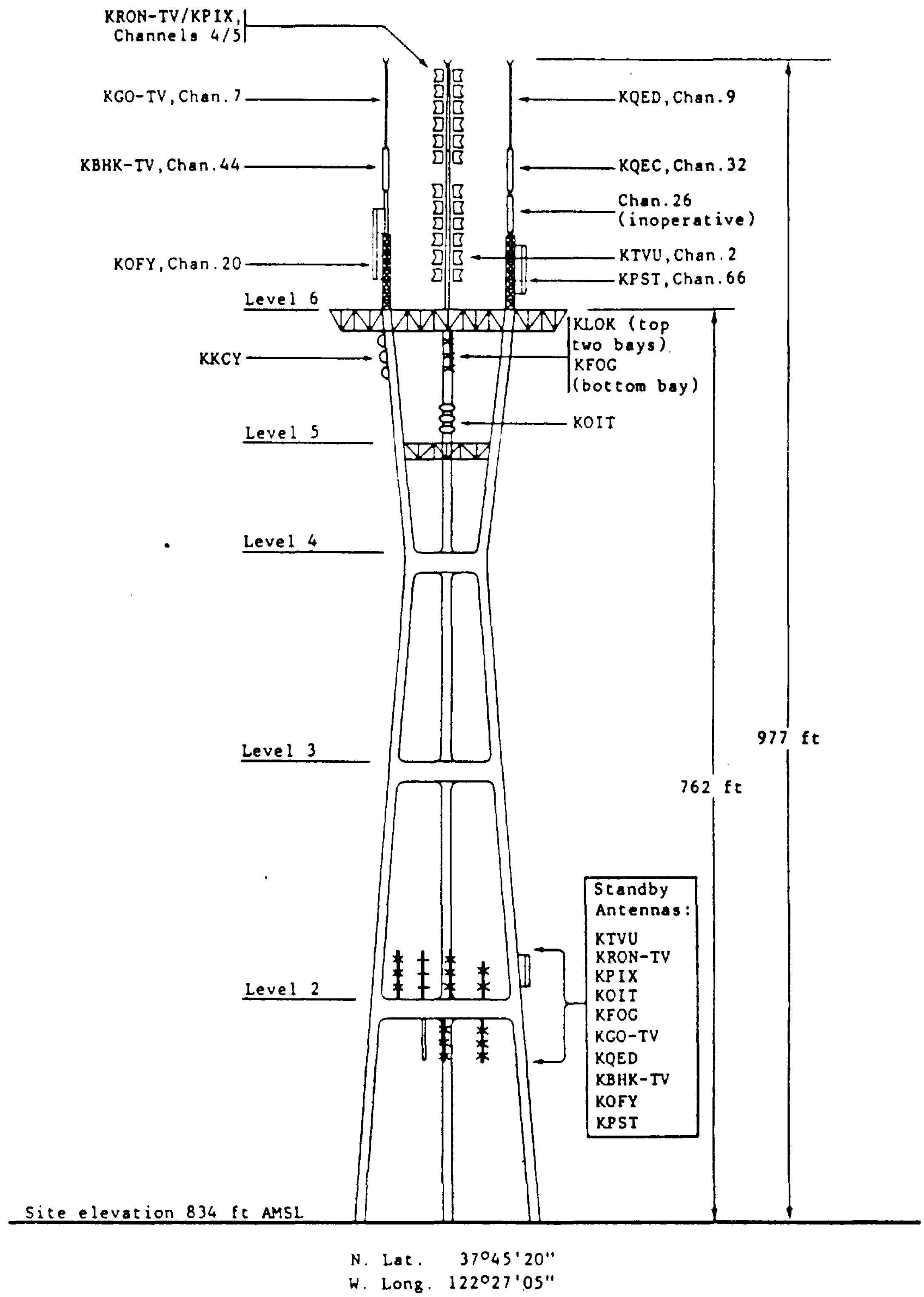
LS/WP2-0165
17 DEC 91

SKETCH SHOWING HDTV ANTENNA PLACEMENT. A SUGGESTION WOULD BE TO ADD 3 TO 4 FEET TO THE OUTRIGGERS FOR CLEARANCE FROM THE ANTENNA GUY ANCHOR POINTS.





SKETCH SHOWING HDTV LOW POWER (10KW) 30 FOOT UHF ANTENNA WITH ABOUT 4 FEET ADDED TO OUTRIGGER FOR CLEARANCE OF ANTENNA GUY ANCHOR POINTS.



TOWER IS PAINTED AND LIGHTED IN ACCORDANCE WITH FAA REQUIREMENTS		**TOWER ELEVATION** VIEW LOOKING WEST MARCH 1986
HAMMETT & EDISON, INC. CONSULTING ENGINEERS SAN FRANCISCO	SUTRO TOWER INC. SAN FRANCISCO CALIFORNIA	

ANDREW

Andrew Corporation
10500 West 153rd Street
Orland Park, IL U.S.A. 60462
Tel: (708) 349-3300
Telex: 25-3897
FAX: (708)349-5943
Cable WERDNA

9 October 1991

Sutro Tower, Inc.
Mr. Donald Lincoln, DE
250 Palo Alto Avenue
San Francisco, CA 9414-2198

Dear Don:

It was a pleasure speaking with you today regarding the future antenna requirements for HDTV. The Andrew ALP-Series UHF antenna was designed with a long term goal of being HDTV compatible at a low cost regarding windloading constraints on existing towers. I have enclosed our Bulletin 1574A and pattern specifications for the ALP-Series antennas.

I have also enclosed a copy of a paper presented by Geza Dienes at NAB 1990 on "The Antenna/Transmission Line System and HDTV". After your review of this information, please do not hesitate to give me a call if you have questions or comments.

Thank you for your interest in Andrew Broadcast Products. I look forward to speaking with you again in the near future.

Sincerely,

Kerry W. Cozad
Antenna Engineering Manager

cc: B. Cohen

Enclosures

Fi/KWC.1000

ANDREW

THE ANTENNA/TRANSMISSION LINE SYSTEM AND HDTV

Geza Dienes
Andrew Corporation
Orland Park, Illinois

ABSTRACT

To produce the improved picture quality required for ATV transmission, extra information beyond that needed for the NTSC system is required. This paper examines how the transmission line and antenna system might affect HDTV transmission, especially in systems using the presently allocated 6-MHz bandwidth.

Some important antenna system parameters and their influence on signal transmission are examined, such as: 1) Return loss (VSWR) and ghosts; 2) RF pulse testing, and what to look for; 3) Group delay: how much is too much? 4) Group delay distortion as a measure of system quality; 5) Nonlinear components, and the generation of harmonics; 6) Antenna gain and gain stability; 7) Frequency sensitivity; 8) Time varying parameters (wind deflection, amplitude modulation caused by mechanical deficiencies, etc.); and 9) The multi-antenna environment.

The question of improvements likely to be needed in the present systems for the accommodation of future requirements is examined, and steps to achieve these improvements are suggested.

INTRODUCTION

Improved quality ("high-density") TV broadcast systems are now on the horizon. In the U.S., in Europe and in Japan, new designs are nearing readiness for market. Whatever form HDTV finally assumes, one thing is certain: Improved resolution will require transmission of television signals over a different frequency spectrum from that presently in use. Modification of existing hardware is likely to be required as well.

Most if not all of the proposed transmission schemes require a wider frequency spectrum to accommodate increased signal density. Some of the proposed HDTV transmission systems will fit within the existing 6-MHz-wide channel, but will need greater system linearity than the NTSC transmission standard. Some experts think that the transmission system specifications will impose an amplitude linearity of better than 0.25 dB and a maximum phase linearity of 2.0 degrees over the 5- or 6-MHz bandwidth of the video signal.

Transmitter manufacturers have claimed for some time that the transmitters will comply with the above specifications. However, nonlinear distortion caused by the transmitter may well be far less than the echo distortion caused by the antenna and transmission line connected to it.

The purpose of this paper is to examine the transmission line and antenna system of a typical broadcast facility, with a view toward 1) its effect on the transmitted signal, and 2) how this will impact HDTV signal transmission. The nature and degree of various types of signal distortion will be evaluated, and improvements suggested. These will be related to the problem of transmitting signals for the high-density receiving systems currently envisioned.

TRANSMISSION LINE

Transmission line may affect a signal traversing it by:

- Reducing the amplitude of the signal (line attenuation).
- Changing the arrival time at the antenna (phase fluctuations).
- Generating signals of new frequency by mixing existing existing signals (nonlinear mixing).
- Introducing echo distortion (mismatched voltage standing wave ratio [VSWR] of components and termination).

Transmission line signal distortion varies greatly by whether the line is dispersive or nondispersive.

Coaxial transmission line is nondispersive: waves travelling through it have the same velocity of propagation throughout its usable frequency range. On the other hand, waveguide of any kind is dispersive, that is, velocity of wave propagation varies as a function of wave frequency.

Attenuative Distortion

The degree of signal reduction by attenuation varies by frequency, i.e., attenuation and signal reduction become greater as frequency rises. For most transmission lines, the change in attenuation over a 6-MHz band is ıegligible; for dispersive lines such as waveguide, however, attenuation changes may be significant near the waveguide's cut-off frequency. High-power coaxial lines and well-designed waveguide runs, though, will produce attenuation changes of less than 0.05 dB over a television channel. Figure 1 shows typical values for attenuation as a function of frequency for waveguide and coaxial line.

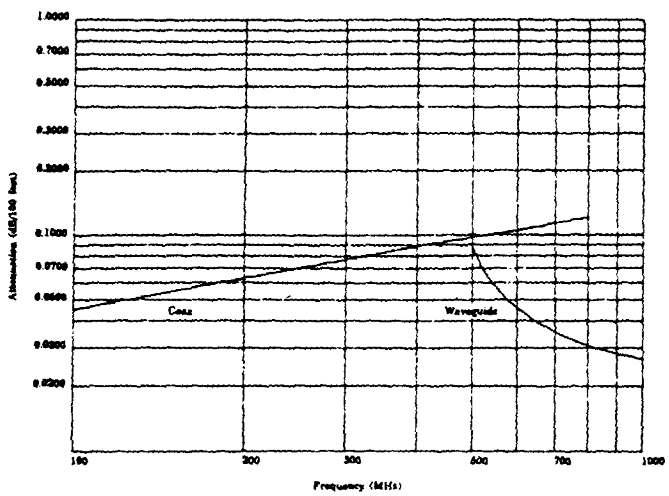


Figure 1. Typical values for attenuation as a function of frequency for waveguide (dispersive) and coaxial (nondispersive) line.

Linear Group Delay Distortion

Since wave propagation velocity does not vary in coaxial lines, there is no problem caused by changes in :he arrival time of signals having different frequencies. Vaveguide, however, may introduce a 10- to 30-anosecond time difference between the travel time of ıe lowest- and the highest-frequency signals in a levision channel. Differential time delays of this agnitude are generally either negligible or correctable.

e expression for the velocity of propagation (V_P) in 'eguide is:

$$= C \times \sqrt{1 - (F_c/F)^2} \qquad (1)$$

·e

= Sp of light in free space (0.9835 ft./nsec)

: = Cutoff frequency of the waveguide

F = Frequency of operation

As an example of the foregoing, assume Channel 30, with 1600-foot-long run of 15-inch-diameter waveguide that has a cutoff frequency of 461.13 MHz. The lowest video frequency is 651.25 MHz; highest video frequency is 655.75 MHz.

With F at 651.25 MHz, the expression is:

$$V_P = 0.9835 \times \sqrt{1 - (461.13/651.25)^2} = 0.69450 \text{ ft/nsec}$$

With F at 655.75 MHz,

$$V_P = 0.9835 \times \sqrt{1 - (461.13/655.75)^2} = 0.69926 \text{ ft/nsec}$$

With F at 651.25 MHz, 1600 feet of waveguide, time of propagation (T_1) is expressed as

$$T_1 = 1600/0.69450 = 2303.8 \text{ nsec}$$

For the same length, at 655.75 MHz,

$$T_2 = 1600/0.69926 = 2288.13 \text{ nsec}$$

Time difference $(T_1 - T_2) = 2303.8 - 2288.13 = 15.67$ nsec.

Figure 2 presents the velocity of propagation as a function of frequency for wave- guide having a cutoff frequency of 461.13 MHz (15-inch-diameter circular waveguide).

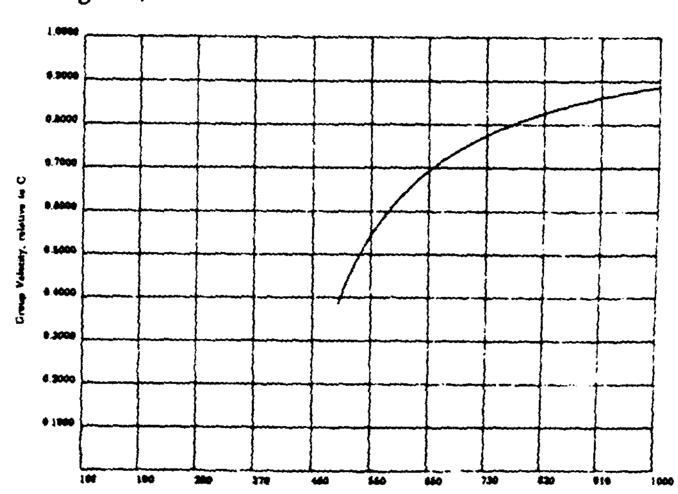
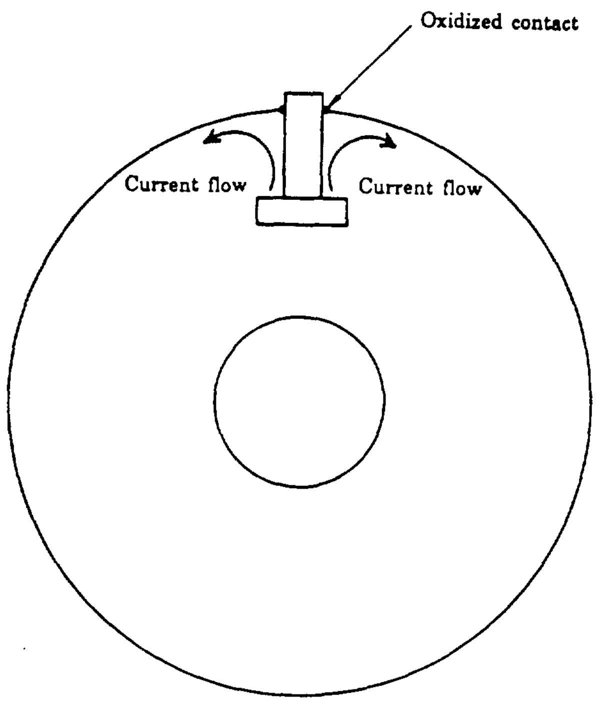


Figure 2. Velocity of propagation as a function frequency for waveguide having a cutoff frequenc 461.13 MHz. (Normalized to the speed of light

Mix-Generated Frequencies

Most transmission line has some contacting surfaces made of copper or copper alloys. Oxidized copper is a rectifier, and can act as a nonlinear device in transmission line. When current, induced by more than one frequency, flows through an oxidized copper contact area, the resultant mixing of frequencies will generate a new frequency. The amplitude of the new frequency depends on the power level of the original signals and on the efficiency of the mixer. This is not a problem with NTSC television signals, but may merit consideration in other systems. Figure 3 depicts current flow in a tuner.



Cross-sectional view, coaxial cable

Figure 3. Current flow in a tuner.

Echo Distortion

As their name implies, echo distortions are caused by echoes in the transmission line. These may be reflections of the signal from some discontinuity in the line or from a mismatch of the load. The extent of distortion depends on the amplitude of the echo and the attenuation and electrical length of the line.

Echo distortions may be increased by the intentional mismatch that exists between a high-power transmitter (which has a low impedance) and the transmission line (which has a relatively high impedance), as follows:

The signal generated by the transmitter enters the transmission line, travels toward the antenna, and encounters a discontinuity in the transmission line. Some portion of the signal will be reflected by the discontinuity, and will travel back toward the transmitter. When the returning signal arrives at the transmitter port, it encounters a large mismatch, and is reflected again toward the antenna. Eventually this signal will be radiated by the antenna as a delayed image, experienced by viewers as the phenomenon of "ghosts" in the received image. (See Figure 4.)

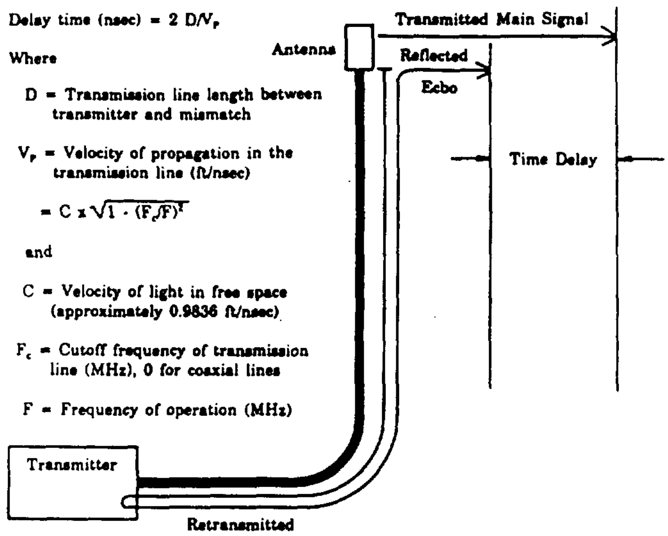


Figure 4. Echo in a transmission line.

Another aspect of distortion caused by echoes is the "monster echo." Consider the signal entering the antenna terminal. This signal will be the sum of the main signal -- the directly radiated signal -- and of all of the echoes that may be created by the line.

These effects may combine in phase to produce a monster echo, here termed E_{max}, producing the greatest disturbance of all. Figure 5 shows vector addition of echoes.

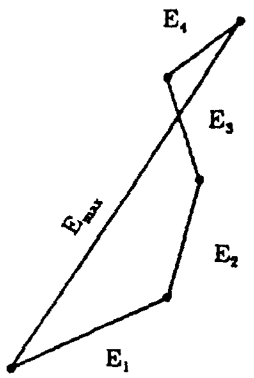
The expression for summing the echoes is:

$$E_{max} = E_1 + E_2 + \ldots E_n \qquad (2)$$

E_1 and E_2 are the echoes caused by various discontinuities numbered

1 . . . n

and are expressed as a fraction of the main signal. Naturally, these are complex quantities having both amplitude and phase parameters. The main signal will



In random phase, E_{max} is smaller than when echoes add in phase, as below

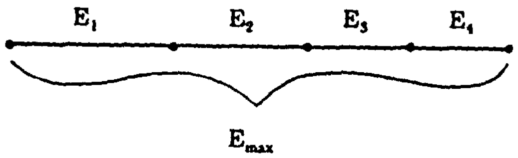


Figure 5. Vector addition of echoes.

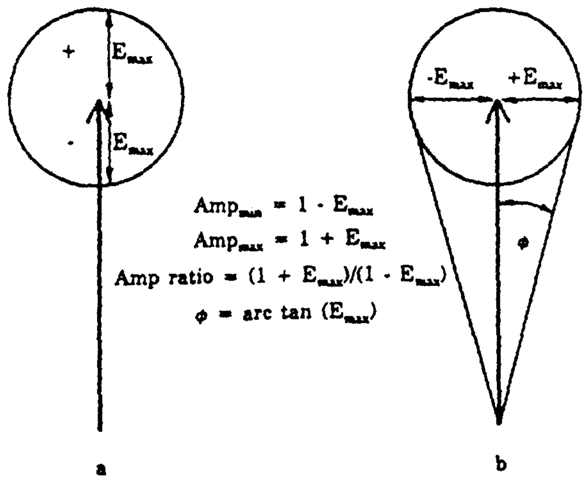


Figure 6. Vector addition of main signal and E_{max}.

serve as the point of reference, and is assumed to have a magnitude of 1.0.

The actual signal amplitude will be the sum of the main signal and E_{max}. From Figure 6a, the resultant signal will have the largest amplitude when E_{max} adds in phase with the main signal, and have the smallest amplitude when E_{max} is out of phase with the main signal.

The amplitude variation is expressed as a ratio of the minimum signal to the maximum signal:

$$\text{Amp ratio} = (1 + E_{max})/(1 - E_{max}) \qquad (3)$$

Or, in decibels,

$$\text{Amp ratio, dB} = 20 \log 10 \text{ (Amp ratio)} \qquad (4)$$

'he phase of the signal entering the antenna will also e affected. The greatest phase change will result 'hen E_{max} is in phase quadrature with the main signal. See Figure 6b.)

here r two possibilities, one each for the positive -90°) d negative (-90°) phase quadrature. The agnitude of the resulting phase change may be pressed as:

$$\text{Phase change} = \text{Arc tan } (E_{max}) \qquad (5)$$

As there are two cases, one for $+E_{max}$ and one for $-E_{max}$, the total phase change is expressed as:

$$\text{Total phase change} = 2 \text{ phase change} \qquad (6)$$

Assuming a near-perfect antenna/transmission line system, we may expect that the antenna and elbow complex VSWR is 1.02, and the rest of the transmission line is perfect.

A VSWR of 1.02 indicates an echo level of

$$(1.02 - 1)/(1.02 + 1) = 0.01$$

The amplitude change therefore is

$$20 \log (1.01/0.99) = 0.172 \text{ dB}$$

The phase change is

$$2.0 \text{ arc tan } (0.1) = 1.146^\circ$$

TESTING

Tests to determine how well a transmission line meets system requirements, aside from attenuation measurement, fall into two kinds. The first is designed to show how well the transmission line will work together with other system components; the second can be used to determine how much signal distortion the line will produce.

VSWR or Return Loss Testing

Voltage standing wave ratio (VSWR) testing common method. Testing may be done discrete frequencies to cover a TV chnnel, or sweep frequency measurement may be used. The magnitude of the VSWR indicates how closely the line impedance remains the same as the termination, or how well the line matches the load as frequency is varied. This method will provide some insight into how well the impedance of the transmitter output and other components such as the antenna will mate with the line. The magnitude of the VSWR alone is not a reliable indicator of possible ghosting. Skillful interpretation of the frequency vs. VSWR curve is necessary to draw any meaningful conclusions about the timing of the echoes in the line.

RF Pulse Testing

This method is used to find the sources of reflections, and to measure the amplitude of the reflected signal in a transmission line. It is an excellent indicator of possible ghosting, but will not directly show the impedance behavior of the transmission line.

In this method, a short RF pulse is generated and injected into one end of the line. The reflected pulse is then compared in amplitude to the incident one. The time it takes for the reflected pulse to appear indicates the electrical distance to the source of the reflection; the amplitude indicates the severity of the problem. The pulse is shaped, so it represents the frequency content of an NTSC transmission.

The amplitude of the reflected pulse is proportional to the magnitude of the discontinuity that caused the reflection. It is also an excellent indicator of the signal distortion one may expect. The greatest echo level is the sum of all of the reflected pulses. We may safely assume that all of the echoes will add in phase at least once, especially when they originate from a point far from the transmitter. Figure 7 is the result of a typical pulse test.

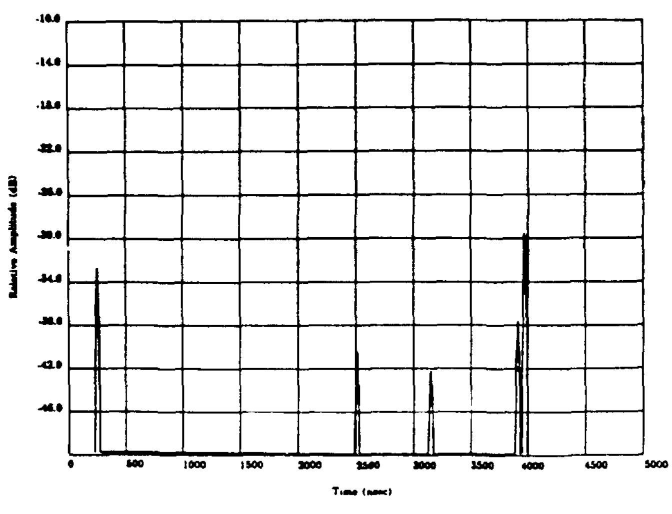


Figure 7. Results of an RF pulse test.

The location of the source of reflection is also very important. A reflected signal generated very close to the transmitter will travel about the same length of line as the main signal. The "ghost" produced by this echo appears barely displaced from the original picture, so it is undiscernible to the naked eye. The phase relationship between the main and reflected signals will also be essentially constant constant with frequency. The sum of the main signal and the echo will no longer exhibit the cyclic amplitude and phase variation damaging to picture quality.

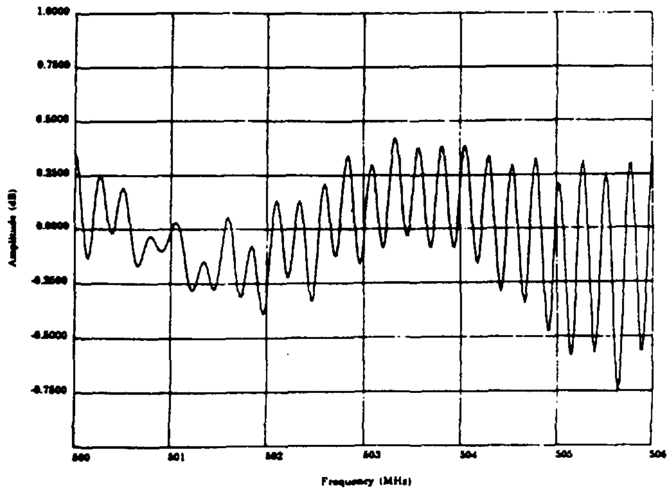


Figure 8. Amplitude ripple vs. frequency caused by echoes.

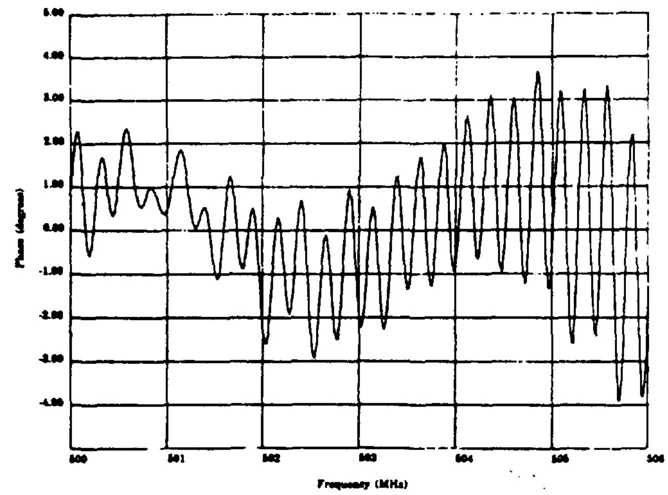


Figure 9. Phase ripple vs. frequency caused by echoes.

A reflection far away from the transmitter causes the reflected signal to travel a much longer distance than the main signal. Even a small change in frequency will cause a large change in the phase between them. The summation of the reflected and main signals will go through as many cycles as the phase between them does. Figures 8 and 9 are the calculated amplitude and phase vs. frequency behavior of a 2000-foot transmission line with an antenna.

THE ANTENNA

For purposes of simplicity, think of the antenna as the device that connects the end of the transmission line to the customer. Of course the connection is not hard-wired, but it is helpful to view the antenna in this manner, omitting any other influencing factors such as propagation, receiving system, terrain, etc.

Input Impedance

The signal passing through the antenna will have to enter it, so the input impedance of the antenna will affect its amplitude and phase.

The amplitude of the signal entering the antenna will be reduced by the amount which is reflected due to the mismatch between the transmission line and the antenna. The phase of the signal will be proportional to real and reactive components of the complex input impedance. Figure 10 shows a typical antenna's impedance on a Smith Chart. Figure 11 shows the corresponding reflection coefficient vs. frequency characteristics for the same antenna.

The amplitude reduction (i.e., the amount of signal rejected) is not very much for the VSWR levels normally encountered. The reduction of signal level in dB is:

$$\text{Loss in dB} = 10 \log \left(1 - \{[\text{VSWR} - 1]/[\text{VSWR} + 1]\}^2\right)$$

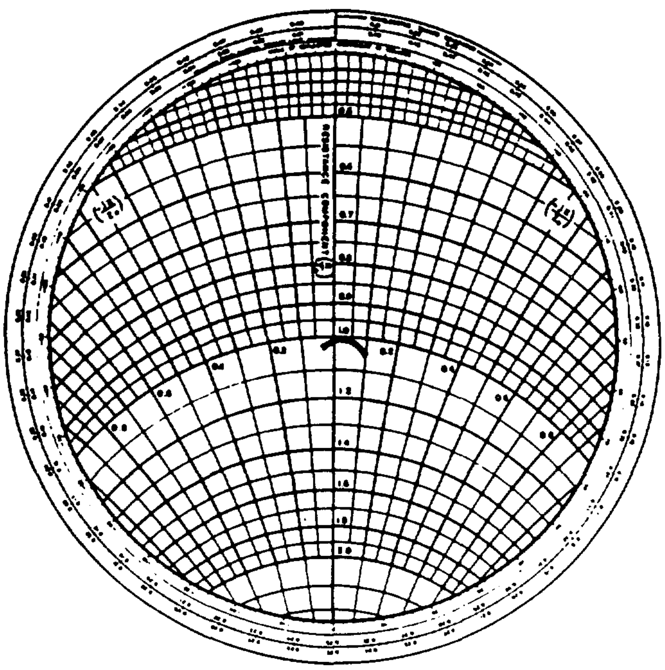


Figure 10. Impedance vs. frequency for a typical antenna.

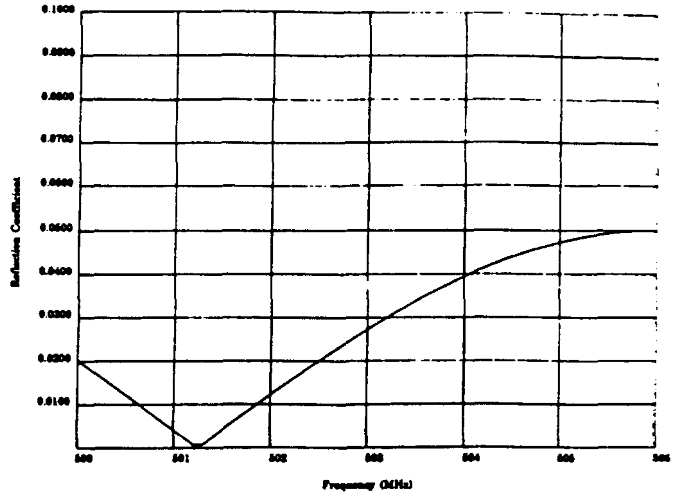


Figure 11. Reflection coefficient vs. frequency for a typical antenna.

When the VSWR is at 1.1, the loss is negligible, about 0.01 dB.

The phase of the signal is determined by the ratio of real to reactive components of the input impedance, or

$$\text{Phase} = \arctan(\text{reactance}/\text{resistance}) \tag{7}$$

Assume a case where the VSWR of the antenna is 1.0 at midband, and 1.1 at the band edge. The phase at midband will be the norm, or zero degrees, since

$$\arctan(0/1) = 0$$

The phase at the low end is

$$\arctan(0.1/1.05) = 5.44^\circ$$

The phase at the high end is

$$\arctan(-0.1/1.05) = -5.44^\circ$$

The total phase variation is 10.88°!

Even for the most perfect system, mentioned before, the total phase change of the signal entering the antenna is

$$\text{total phase} = 2 \arctan(0.02/1) = 2.29^\circ$$

(It is assumed that the reactance is about 0.02 for a VSWR of 1.02.)

The HDTV systems currently under proposal may need transmission line systems with improved performance. The improvement is not likely to result from improved component specification. Correction circuits may be used, or the mismatch between the transmitter and the transmission line needs to be reduced.

The correction circuits may either reduce the signal distortion caused by the transmission system by some method of pre-emphasis or post-emphasis correction, or interrelate the various signal levels to estimate the correct one.

Echo distortions may be reduced in a number of ways, all aimed at reducing or eliminating the echoes:

■ Increase transmitter output impedance to correspond to the impedance of the transmission line. This would be a highly unpopular solution, because the transmitter efficiency would be drastically reduced. Only about one-half of the transmitter power would be available as input to the transmission line, but the echoes would be absorbed by the transmitter, and eliminated.

Transmission Line				
Pulse	Location	Distance (feet)	Reflected Pulse Amplitude (dB)	Reflected Pulse Amplitude (Ratio)
1	bottom elbow	120	-34	0.0200
2	line	1278	-44	0.0063
3	line	1600	-47	0.0045
4	top elbow complex	1990	-40	0.0100
Antenna				
1	antenna input	2000	---	0.0500
	TOTAL (sum of all reflected signals)			0.0808

Use the maximum measured VSWR within the 6-MHz channel.

RF pulse test measurements produced the amplitude values shown. The reflected pulse amplitude relative to the incident, or main signal, is calculated using the expression:

Relative amplitude $= 10^{-dB/20}$

The reflection coefficient for a VSWR of 1.1 = 0.05

Max/min amp ratio = (1 + 0.0808)/(1 - 0.0808) = 1.175

Amplitude ratio, dB = 20 log (1.1418) = 1.41 dB

Phase change, deg = arc tan (0.0662) = 4.62 deg

Total phase change, deg = 2 (3.785) = 9.23 deg

Figure 12. Worksheet: Calculating amplitude and phase distortion.

■ Reduce echo reflections from the transmitter by absorbing the signal travelling toward the transmitter. This may be accomplished with an isolator. The isolator is a directional device capable of allowing signal propagation in one direction, but greatly attenuating it in the other. High-power isolators are now becoming available for this purpose.

■ Improve the antenna and transmission system by reducing or eliminating the mismatch at the point where it occurs. This requires the use of the pulse technique, or perhaps an improved system design, so the location of mismatch may be determined with a high degree of accuracy (within 24 inches).

■ Improve the antenna input impedance so that the match between the antenna and the transmission line is made lower than is provided by the currently accepted VSWR specification of 1.08 to 1.1, bringing it to a range of from 1.02 to 1.03. The antenna tuning should not be optimized to a single frequency (i.e., the visual carrier). The broader spectrum of high-density TV will require a low VSWR over a wider band. Depending on the modulation technique used, this may encompass most of the available 6-MHz channel.

The antenna will cause phase and amplitude changes, due to its frequency-dependent input impedance and radiation pattern. The input impedance is more likely to produce phase changes, the radiation pattern to produce amplitude variations. Careful antenna design reduces the effect of both. The absolute worst-case results are shown in Figure 13. The calculation was performed for the parameters shown on the worksheet, Figure 12.

(In each case, variations are calculated by simple addition)

Maximum amplitude variation due to echoes	1.41 dB
Maximum amplitude variation due to antenna	2.10 dB
Maximum differential gain	3.51 dB
Maximum phase variation due to echoes	9.23 deg
Maximum phase variation due to antenna impedance	2.86 deg
Maximum differential phase	12.06 deg

Figure 13. Worksheet: Calculating worst case distortion.